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HEAT TREATMENT STUDIES TO IMPROVE THE HOT SHORT DUCTILITY OF RENE' 41 ALLOY SHEET

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HEAT TREATMENT STUDIES TO IMPROVE THE HOT SHORT DUCTILITY OF RENE' 41 ALLOY SHEET

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Project 281

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R.C. Kay and J.C. Reeves - Thermal Cycling Procedures

A. Mardarian - Mechanical Property Tests

R.C. Kay and J.C. Reeves - Compilation and Analyses of Data

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I. SUMMARY

Heat treat studies were conducted to develop thermal cycling procedures for improving the mechanical properties of Rene' 41 with particular emphasis on elongation in the critical temperature range from 1400° to 1700°F. Integrated with improvement of mechanical properties were utilization of pre-established brazing cycles and long-time prolonged aging of Rene' 41 alloy sheet to simulate the time-temperature operation of a hot wall structure.

Specimens fabricated from 0.010- and 0.063-inch thick Rene' 41 sheet were subjected to eight different thermocycling procedures. The specimens were equally divided and aged at 1650°F for 50 hours in an oxidizing or in a nonoxidizing (vacuum) atmosphere. Short time tensile and stress-rupture tests were conducted to determine (1) tensile properties at room temperature and 1500°F, and (2) stress-to-rupture in 100 hours at 1600°F.

Test results are summarized as follows:

1. Ultimate tensile and yield strengths for both 0.010- and 0.063-inch sheet material were appreciably higher than values shown in published data at both room temperature and 1500°F.

2. Elongation values at 1500°F were improved 100 percent for vacuum-aged 0.010-inch Rene' 41 sheet specimens.

3. Elongation values exhibited by 0.063-inch Rene' 41 sheet specimens displayed improvements ranging up to 500 percent at 1500°F for vacuum-aged specimens. Air aged specimens showed improvements ranging from 100 to 400 percent.

4. One-hundred hour stress-rupture properties of vacuum and air aged specimens indicated no significant lowering of stress levels. However, vacuum-aged specimens generally exhibited higher stress levels than air aged specimens. All stress-rupture tests were conducted in an oxidizing atmosphere. Elongation percentage improvements at 1500°F were highly significant for future utilization of this alloy. Further effort in this prolonged overaging is required to verify the initial results.

II. INTRODUCTION

Previous testing of the Rene' 41 alloy sheet resulted in a marked decrease in ductility through the 1400° to 1700°F range. The heat treatments used were those recommended by the material producers for the best stress-rupture properties. This recommended heat treatment of 2150°F for 30 minutes with a solution anneal followed by 1650°F for 4 hours of precipitation aging resulted in extremely low elongation percentages (approximately 5 percent) in the 1400° to 1700°F range. A need for an investigation of the effects on Rene' 41 alloy sheet at long time elevated temperature exposure was indicated. The critical factor was the determination of base metal mechanical property decline.

The program reported herein was initiated (1) to develop optimum thermal cycling procedures in order to increase elongation values in the 1400° to 1700°F range, and (2) to determine the integrity of the base metal after long time exposure. For comparative purposes, equal quantities of 0.010- and 0.063-inch thick sheet specimens were thermal cycled and precipitation hardened in an oxidizing atmosphere and in a vacuum at 1650°F for 50 hours, prior to short time tensile and stress-rupture testing.

III. EXPERIMENTAL PROCEDURES

A. General Considerations

Equal quantities of test specimens were prepared from 0.010- and 0.063-inch thick Rene' 41 alloy sheet. These specimens were divided into two groups by thickness and redivided into four groups of each thickness for heat treatment as noted in Table I, or two thicknesses for each heating method and thermal cycle designated.

Vacuum furnace radiant heat was utilized for both the 1950° and 2100°F hold time of ten minutes. This simulated the pre-established brazing time-temperature cycle and corresponded roughly to solution annealing temperatures for the Rene' 41 alloy. Vacuum was maintained at one micron or less.

Inert gas induction heating was utilized for both the 1950° and 2100°F hold time of one minute. This procedure simulated a solution temperature exposure but excluded the anticipated detrimental effects of long hold time, thereby permitting a comparison of long time versus short time temperature exposure.

Fifty percent of the specimens of each sheet thickness and each heating method were precipitation aged at 1650°F for 50 hours in moving air. The remaining specimens were precipitation aged at 1650°F for 50 hours in vacuum. This aging simulated anticipated time-temperature hot wall environmental exposure for both moving air and vacuum conditions.

B. Heat Treatments

During the radiant vacuum solution heat treatments, specimens were hung in the vertical position to reduce warpage. Cooling from the heat treatment temperatures of 1950° and 2150° to 1400°F required 2 to 5 minutes, which is well within the permissible maximum of 15 minutes. During heating, holding, and cooling, a vacuum of approximately 0.5 micron was maintained.

During the induction inert gas (Argon) heat treatments (annealing), heating of the 0.010-inch thick specimens by direct induction was not possible. Therefore, all specimens were heat treated individually in a fixture. The fixture was induction heated and, in turn, heated the specimen by conduction.

The heating time from room temperature to the heat treatment temperatures of 1950° and 2150°F was between 1-1/2 and 2-3/4 minutes. After holding at temperature for one minute, the specimens were quickly cooled. The time required to reach 1400°F was between 1/3 and 2-1/3 minutes.

During the 50-hour air aging treatments, specimens were suspended from one of the loading holes on a pin and aged in a brazing furnace. Provisions were made for replenishing the air at 25 cfh. The vacuum aged specimens were bundled and sealed in a retort made of 5-inch diameter by 0.500-inch wall stainless steel pipe. The retort and vacuum gage were checked for leaks with a helium leak detector. The retort and specimens were outgassed of contaminants by pumping for 24 hours at room temperature followed by 24 hours at various elevated temperatures (all below temperatures that would cause any metallurgical changes). After outgassing, the temperature was raised to 1650°F and held for 50 hours. A vacuum of 1 micron or less was maintained.

IV. RESULTS AND DISCUSSION

A. Tensile Properties

Mechanical property tests at room temperature and 1500°F were conducted on completed specimens.

The tensile properties of 0.010- and 0.063-inch Rene' 41 sheet specimens utilizing various heat treatments are presented in Tables II to IX. The tensile properties exhibited slightly more scatter than usually displayed; however, this scatter can be attributed to the unique approach to heat treat procedures. Of special significance is the great increase in elongation values exhibited by 1650°F for 50-hour vacuum aged specimens, particularly the 0.063-inch sheet.

The increase in ultimate tensile strength of vacuum aged specimens over that of air aged specimens ranged as high as 15,000 psi. Average increases in ultimate tensile strength were 8,000 to 12,000 psi.

Tables II to IX show short time tensile properties achieved at room temperature and 1500°F, utilizing the heat treatments designated in Table I.

Table II (Heat Treat Group 1, Air Aged) presents ultimate tensile and yield strengths for 0.010-inch sheet that are higher than the published data values. The elongation values were equivalent. The ultimate tensile and yield strength values for 0.063-inch sheet were considerably higher at room temperature and 1500°F than the published data. Elongation also showed a marked improvement. These specimens were aged in air at 1650°F for 50 hours, as noted for Heat Treat Group 1 (Table I).

Table III (Heat Treat Group 2, Vacuum Aged) presents higher ultimate tensile and yield strengths for 0.010-inch sheet than for the air aged specimens (Table II). Elongation values were significantly higher at 1500°F, showing an increase of approximately 100 percent for both 0.010- and 0.063-inch sheet. This increase may be attributed to the beneficial aspects of overaging in vacuum, after recovery resolutioning at 1950°F.

Table IV (Heat Treat Group 3, Air Aged) presents ultimate tensile, yield, and elongation percentages that were higher for both 0.010- and 0.063-inch sheet at room temperature than those in Table I. However, no significant trend is apparent at 1500°F. The ultimate tensile and yield strength values were slightly higher for 0.010-inch sheet and averaged out the same for 0.063-inch sheet. Elongation for 0.063-inch sheet at 1500°F showed improvement over published data.

Table V (Heat Treat Group 4, Vacuum Aged) presents ultimate tensile and yield properties that were not significantly higher or lower for either 0.010- and 0.063-inch sheet than those exhibited by the air aged specimens listed in Table IV. However, the elongation values at 1500°F were noticeably improved.

Table VI (Heat Treat Group 5, Air Aged) presents ultimate tensile and yield strength properties that were comparable to the values listed in Tables II and III (2100°F for 10-minute heat treatment). The elongation values for the 0.010-inch sheet were relatively low. Elongation values at 1500°F for the 0.063-inch sheet showed a considerable superiority over that of the air aged specimens listed in Table II.

Table VII (Heat Treat Group 6, Vacuum Aged) presents elongation values that were greatly superior to the published data. The ultimate and yield strengths were equivalent to the higher values listed in the foregoing tables. The elongation averages out to a greater percentage than for the air aged specimens listed in Table VI.

Table VIII (Heat Treat Group 7, Air Aged) presents ultimate, yield, and elongation values that were equivalent to those listed in Table VI for both the 0.010- and 0.063-inch sheet material.

Table IX (Heat Treat Group 8) presents the results of vacuum aging of specimens to improve ductility as demonstrated by the consistently higher values exhibited in Table IX versus the values of Table VIII air aged specimens. Table X summarizes the average mechanical properties for 0.010-inch sheet of Tables II to IX. The results shown indicate a positive superiority of vacuum aged over air aged specimens.

Table XI summarizes the average mechanical properties for 0.063-inch sheet of Tables II to IX. The vacuum aged specimens were quite superior to the air aged specimens. However, the air aged specimens showed a 100 percent improvement over conventional published data properties.

B. Creep and Stress Rupture Properties

Creep and 100-hour stress-rupture tests were conducted on thermal cycled specimens selected at random from the various heat treatments. These tests were conducted in an air atmosphere to simulate the predicted service conditions to which Rene' 41 sheet material would be exposed.

The results of the various creep extensions and rupture tests are presented in Tables XII and XIII.

Figures 1 to 8 are plots of the percent plastic creep and stress-rupture 100-hour properties of 0.010-inch Rene' 41 sheet. The results are compared with data derived from previous tests. However, only stress-rupture will be discussed due to its primary importance.

Figure 1 (Heat Treat Group 1, Air Aged) shows that the 100-hour stress-rupture value of 18 Ksi compares favorably with conventional heat treat values of 20 Ksi.

Figure 2 (Heat Treat Group 2, Vacuum Aged) shows a 100-hour stress-rupture value of 21 Ksi. (Reference to Table X shows eleven percent elongation at 1500°F.) These values indicate that the stress-rupture properties were relatively unaffected using vacuum overaging with this heat treatment.

Extrapolation of Figures 3 and 4 as shown (Heat Treat Groups 3 and 4, Air and Vacuum Aged, respectively) indicates a decline from published stress-rupture data properties for both heat treatments. This decline is attributable to maintenance of stable carbide M_6C, resulting in no reprecipitation of brittle carbide $M_{23}C_6$ (which tends to increase stress-rupture levels).

Figures 5 and 6 (Heat Treat Groups 5 and 6, Air and Vacuum Aged) show that the vacuum aged specimens were 4 Ksi higher at 100-hour stress-rupture than the air aged specimens. Stress levels of approximately 19 Ksi were achieved by the vacuum aged specimens and are reasonably close to published data values. This increase of stress levels indicates some dissolving of M_6C and resultant reprecipitation of $M_{23}C_6$.

Figures 7 and 8 reflect the same general trend of Figures 5 and 6. The stress levels were significantly higher for the vacuum aged specimens.

Overall, Figures 1 to 8 indicate no significant lowering of stress-rupture properties for any of the eight heat treatments. The vacuum aged specimens generally exhibited slightly higher properties than the air aged specimens.

Figures 9 through 16 present percent plastic creep and 100-hour stress-rupture properties of 0.063-inch sheet. The results are compared with data published by the Haynes Stellite Company, Kokomo, Indiana, in Brochure No. F 30 155A.

Figure 9 (Heat Treat Group 1, Air Aged) shows stress levels that were slightly lower than the published data (23 Ksi versus 26 Ksi). The 10 percent decrease is more than offset by the improvement in the elongation as shown in Table I.

Figure 10 (Heat Treat Group 2, Vacuum Aged) shows that the stress-rupture levels were recovered. This demonstrates some superiority of vacuum over-aging for this heat treatment.

Figures 11 and 12 (Heat Treat Groups 3 and 4, Air and Vacuum Aged) show lower values as compared with Figures 9 and 10. The vacuum aged specimens had slightly higher stress levels.

Figures 13 and 14 (Heat Treat Groups 5 and 6, Air and Vacuum Aged) show no appreciable recovery in properties over Heat Treat Groups 3 and 4. The vacuum aged specimens exhibited superiority over the air aged specimens.

Figures 15 and 16 (Heat Treat Groups 7 and 8, Air and Vacuum Aged) show values that compare with Heat Treat Groups 5 and 6, with vacuum aged specimens still retaining superiority.

V. CONCLUSIONS

These data indicate a significant improvement in the ductility of Rene' 41 alloy sheet at the critical operational service temperature of 1500°F. This improvement in ductility is attributed mainly to the 50-hour vacuum aging treatment.

Tensile strength was improved over that shown in published data. Values were appreciably higher at room temperature and 1500°F, for both 0.010- and 0.063-inch material.

The properties achieved in the studies described herein should be considered as preliminary data only. Additional testing is required for substantiation and for firm establishment of design data.

TABLE I

HEAT TREATMENT OF RENE' 41 ALLOY SHEET

Heat Treat Group No.	Heat Treatment	Sheet Thicknesses (inch)
1.	2100°F, 10 min vacuum, 1950°F, 30 min air, 1650°F, 50 hrs air	0.010 0.063
2.	2100°F, 10 min vacuum, 1950°F, 30 min vacuum, 1650°F, 50 hrs vacuum	0.010 0.063
3.	1950°F, 10 min vacuum, 1650°F, 50 hrs air	0.010 0.063
4.	1950°F, 10 min vacuum, 1650°F, 50 hrs vacuum	0.010 0.063
5 & 5a.	2100°F, 1 min ind. inert gas, 1650°F, 50 hrs air	0.010 0.063
6.	2100°F, 1 min ind. inert gas, 1650°F, 50 hrs vacuum	0.010 0.063
7.	1950°F, 1 min ind. inert gas, 1650°F, 50 hrs air	0.010 0.063
8.	1950°F, 1 min ind. inert gas, 1650°F, 50 hrs vacuum	0.010 0.063

TABLE II

TENSILE PROPERTIES OF RENE' 41 ALLOY SHEET
HEAT TREAT GROUP 1

Test Conditions:

Heat Treated = 2100°F, 10 min, radiant vacuum
1950°F, 30 min, air
1650°F, 50 hours air

Strain rates = 0.001 in./in./sec to yield
0.01 in./in./sec to rupture

Heating method = Resistance, air atmosphere

Specimen Number	Sheet Thickness (ins.)	Test Temp. (°F)	Hold Time (min)	Prop. Limit (Ksi)	0.2% Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	Young's Modulus (10^6 psi)	Elongation (% in 2 in.)
1.	0.010	RT	--	79.0	105.5	140.0	29.9	7.5
2.	0.010	RT	--	80.0	110.0	153.0	30.6	8.9
3.	0.010	RT	--	78.5	111.0	151.0	29.7	8.2
4.	0.010	1500	5	57.0	87.0	115.9	22.0	4.5
5.	0.010	1500	5	48.0	77.9	107.8	19.4	4.0
6.	0.010	1500	5	54.0	85.2	111.0	21.9	3.9
1.	0.063	RT	--	88.0	114.0	168.1	31.9	10.8
2.	0.063	RT	--	94.0	116.0	174.0	32.0	12.0
3.	0.063	RT	--	97.0	117.0	172.6	31.4	11.0
4.	0.063	1500	5	77.0	96.8	133.0	21.3	10.0
5.	0.063	1500	5	78.0	96.0	132.0	22.0	12.5
6.	0.063	1500	5	71.0	93.9	106.0	23.0	--*

Notes:

RT = Room temperature

* = Broke outside gage length

TABLE III

TENSILE PROPERTIES OF RENE' 41 ALLOY SHEET
HEAT TREAT GROUP 2

Heat Treatment = 2100°F, 10 minutes radiant vacuum
1950°F, 30 minutes radiant vacuum
1650°F, 50 hours vacuum

Specimen Number	Thickness (in.)	Test Temp. (°F)	Hold Time (min)	Prop. Limit (Ksi)	0.2% Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	Young's Modulus (10^6 psi)	Elongation (% in 2 in.)
1.	0.010	RT	--	98.0	116.0	160.0	32.0	7.1
2.	0.010	RT	--	94.0	116.0	166.5	31.9	8.0
3.	0.010	RT	--	91.0	113.3	168.0	32.0	10.0
4.	0.010	1500	5	59.0	85.2	118.0	21.4	10.0
5.	0.010	1500	5	62.0	84.0	119.0	20.7	15.0
6.	0.010	1500	5	58.0	86.9	120.0	23.0	8.0
1.	0.063	RT	--	88.0	108.0	166.0	29.5	12.5
2.	0.063	RT	--	87.0	108.1	164.3	30.6	11.1
3.	0.063	RT	--	85.0	109.2	173.4	31.7	14.2
4.	0.063	1500	5	67.0	86.2	132.0	22.3	22.0
5.	0.063	1500	5	60.0	87.0	124.0	24.0	21.5
6.	0.063	1500	5	69.0	88.0	123.2	23.2	20.0

RT = Room temperature

TABLE IV

TENSILE PROPERTIES OF RENE' 41 ALLOY SHEET
HEAT TREAT GROUP 3

Test Conditions:

Heat Treated = 1950°F, 10 min, radiant vacuum
1650°F, 50 hrs air

Strain rates = 0.001 in./in./sec to yield
0.01 in./in./sec to rupture

Heating method = Resistance, air atmosphere

Specimen Number	Thickness (ins.)	Test Temp. (°F)	Hold Time (min)	Prop Limit (Ksi)	0.2% Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	Young's Modulus (10^6 psi)	Elongation (% in 2 in.)
1.	0.010	RT	--	82.6	117.0	162.4	30.0	10.1
2.	0.010	RT	--	90.4	119.0	170.0	29.7	12.1
3.	0.010	RT	--	91.0	118.5	170.0	29.9	12.0
4.	0.010	1500	5	61.0	88.1	118.1	21.8	5.7
5.	0.010	1500	5	68.0	93.0	120.0	21.9	5.5
6.	0.010	1500	5	59.0	89.0	112.0	21.8	5.0
1.	0.063	RT	--	94.0	118.3	178.4	31.9	13.4
2.	0.063	RT	--	96.0	118.0	180.0	31.0	--*
3.	0.063	RT	--	93.8	131.3	185.9	32.0	12.5
4.	0.063	1500	5	73.5	94.0	124.0	21.1	11.0
5.	0.063	1500	5	76.0	95.8	124.3	23.9	7.5
6.	0.063	1500	5	76.3	98.1	125.9	23.7	11.0

RT = Room temperature

* = Broke outside gage length

TABLE V

TENSILE PROPERTIES OF RENE' 41 ALLOY SHEET
HEAT TREAT GROUP 4

Test Conditions:

Heat Treated = 1950°F, 10 min, radiant vacuum
1650°F, 50 hrs vacuum

Strain rates = 0.001 in./in./sec to yield
0.01 in./in./sec to rupture

Heating method = Resistance

Atmosphere = Air

Specimen Number	Thickness (ins.)	Test Temp. (°F)	Hold Time (min)	Prop Limit (Ksi)	0.2% Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	Young's Modulus (10^6 psi)	Elongation (% in 2 in.)
1.	0.010	RT	--	96.0	118.1	185.0	31.0	14.0
2.	0.010	RT	--	96.5	120.5	181.0	32.0	10.5
3.	0.010	RT	--	94.8	119.5	180.0	31.4	11.2
4.	0.010	1500	5	52.0	84.1	113.3	20.6	10.0
5.	0.010	1500	5	58.0	86.9	119.0	22.1	12.0
6.	0.010	1500	5	47.0	81.0	109.8	21.3	12.0
1.	0.063	RT	--	92.0	117.5	170.7	31.0	10.6
2.	0.063	RT	--	98.0	123.2	185.0	30.6	15.6
3.	0.063	RT	--	81.0*	107.0*	159.0*	30.0	8.7*
4.	0.063	1500	5	64.5	88.6	128.0	23.9	19.0
5.	0.063	1500	5	64.0	87.0	124.0	23.1	18.0
6.	0.063	1500	5	60.0	86.3	120.0	22.6	21.5

RT = Room temperature

* = Broke at radius

TABLE VI

TENSILE PROPERTIES OF RENE' 41 ALLOY SHEET
HEAT TREAT GROUP 5

Test Conditions:

Heat Treated = 2100°F, 1 min, induction inert
1650°F, 50 hrs, air

Strain rates = 0.001 in./in./sec to yield
0.01 in./in./sec to rupture

Heating method = Resistance, air atmosphere

Specimen Number	Thickness (in.)	Test Temp. (°F)	Hold Time (min)	Prop. Limit (Ksi)	0.2% Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	Young's Modulus (10^6 psi)	Elongation (%, in 2 in.)
1.	0.010	RT	--	81.0	116.0	159.0	30.0	8.9
2.	0.010	RT	--	84.0	120.0	165.5	30.7	9.7
3.	0.010	RT	--	88.0	122.0	171.0	30.5	11.2
4.	0.010	1500	5	59.0	85.5	112.3	21.0	7.0
5.	0.010	1500	5	56.0	84.5	116.5	20.0	5.0
6.	0.010	1500	5	55.0	87.9	112.0	20.1	4.0
1.	0.063	RT	--	95.0	130.0	186.0	31.0	17.3
2.	0.063	RT	--	90.0	120.0	170.0	31.9	9.6
3.	0.063	RT	--	92.5	114.0	167.8	30.5	10.4
4.	0.063	1500	5	79.0	99.0	130.0	22.8	14.0
5.	0.063	1500	5	68.0	94.0	124.3	21.8	19.5
6.	0.063	1500	5	76.0	94.5	130.7	23.9	19.0
1.	0.063	RT	--	91.0	119.0	178.5	31.8	12.4
2.	0.063	RT	--	104.0	127.9	182.0	31.8	13.0
3.	0.063	RT	--	109.0	133.0	178.5	31.9	9.0
4.	0.063	1500	5	70.0	93.5	132.0	22.0	21.0
5.	0.063	1500	5	71.0	92.0	123.9	21.9	16.0
6.	0.063	1500	5	68.0	93.0	122.9	--	2.9

RT = Room temperature

TABLE VII

TENSILE PROPERTIES OF RENE' 41 ALLOY SHEET
HEAT TREAT GROUP 6

Heat Treated = 2100°F, 1 min, induction inert
1650°F, 50 hrs, vacuum

Specimen Number	Thickness (in.)	Test Temp. (°F)	Hold Time (min)	Prop. Limit (Ksi)	0.2% Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	Young's Modulus (10^6 psi)	Elongation (% in 2 in.)
1.	0.010	RT	--	91.5	120.0	182.0	30.0	12.0
2.	0.010	RT	--	95.0	120.3	180.0	31.8	10.6
3.	0.010	RT	--	93.0	121.0	181.0	30.8	10.5
4.	0.010	1500	5	59.9	84.6	113.2	20.1	12.5
5.	0.010	1500	5	54.0	85.0	116.0	20.7	14.0
6.	0.010	1500	5	57.0	84.9	116.1	22.9	4.2
1.	0.063	RT	--	94.0	120.9	182.3	31.6	17.0
2.	0.063	RT	--	86.0	112.8	167.0	30.1	10.4
3.	0.063	RT	--	90.5	115.0	180.0	29.6	15.5
4.	0.063	1500	5	63.0	88.3	120.2	23.9	21.0
5.	0.063	1500	5	60.0	88.9	120.0	23.9	20.0
6.	0.063	1500	5	65.0	92.1	126.1	24.1	14.5

RT = Room temperature

TABLE VIII

TENSILE PROPERTIES OF RENE' 41 ALLOY SHEET
HEAT TREAT GROUP 7

Test Conditions:

Heat Treated = 1950°F, 1 min, induction inert
1650°F, 50 hrs, air

Strain rates = 0.001 in./in./sec to yield
0.01 in./in./sec to rupture

Heating method = Resistance, air atmosphere

Specimen Number	Thickness (in.)	Test Temp. (°F)	Hold Time (min)	Prop. Limit (Ksi)	0.2% Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	Young's Modulus (10^6 psi)	Elongation (% in 2 in.)
1.	0.010	RT	--	90.0	118.0	166.0	29.8	9.9
2.	0.010	RT	--	93.0	120.0	168.6	30.8	9.6
3.	0.010	RT	--	93.8	121.0	173.0	30.9	12.0
4.	0.010	1500	5	56.5	85.4	117.0	18.0	8.0
5.	0.010	1500	5	53.9	86.0	114.6	20.4	5.0
6.	0.010	1500	5	61.0	89.9	114.4	20.7	7.5
1.	0.063	RT	--	94.0	130.0	175.0	31.1	--*
2.	0.063	RT	--	93.0	130.0	174.5	32.0	9.0
3.	0.063	RT	--	99.0	127.5	183.0	32.0	17.3
4.	0.063	1500	5	59.0	88.6	124.7	21.2	11.0
5.	0.063	1500	5	52.0	60.0	120.3	20.4	19.5
6.	0.063	1500	5	58.0	89.3	122.1	22.9	20.0

RT = Room temperature

* Broke outside gage length

TABLE IX

TENSILE PROPERTIES OF RENE' 41 ALLOY SHEET
HEAT TREAT GROUP 8

Heat Treated = 1950°F, 1 min, induction inert
1650°F, 50 hrs, vacuum

Specimen Number	Thickness (in.)	Test Temp. (°F)	Hold Time (min)	Prop. Limit (Ksi)	0.2% Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	Young's Modulus (10^6 psi)	Elongation (% in 2 in.)
1.	0.010	RT	--	87.0	120.0	174.3	31.1	8.7
2.	0.010	RT	--	93.0	118.7	181.7	31.5	11.1
3.	0.010	RT	--	95.0	121.5	183.9	31.6	10.5
4.	0.010	1500	5	48.5	86.0	121.9	21.0	16.5
5.	0.010	1500	5	43.0	74.5	111.5	20.0	16.0
6.	0.010	1500	5	53.0	82.2	123.0	21.9	16.5
1.	0.063	RT	--	96.0	121.8	174.0	30.0	10.5
2.	0.063	RT	--	92.0	120.5	176.5	31.0	13.5
3.	0.063	RT	--	93.5	122.0	181.0	30.0	13.9
4.	0.063	1500	5	56.0	83.0	117.0	22.0	21.0
5.	0.063	1500	5	48.0	75.9	108.0	22.0	22.5
6.	0.063	1500	5	--*	--*	118.1	--*	20.0

RT = Room temperature
* = 0.01 to Rupture

TABLE X

SUMMARY OF TENSILE PROPERTIES OF 0.010-inch RENE' 41 ALLOY SHEET
AT ROOM TEMPERATURE AND 1500°F

Heat Treatment Group (See Table I); Strain rates = 0.001 in./in./sec to yield
0.01 in./in./sec to rupture

Tensile Property (Average)	1	2	3	4	5	6	7	8
	Air	Vac	Air	Vac	Air	Vac	Air	Vac
	Room Temperature							
Ultimate tensile strength (Ksi)	148.0	164.8	167.2	182.0	165.2	181.0	169.2	180.0
0.2% yield strength (Ksi)	108.0	115.1	118.2	119.7	119.3	120.4	119.7	120.0
Proportional limit (Ksi)	79.2	94.3	88.0	95.8	84.3	93.2	92.3	91.7
Elongation (% in 2 ins.)	8.2	8.4	11.4	11.9	9.3	11.0	10.5	10.1
	1500°F							
Ultimate tensile strength (Ksi)	111.5	119.0	114.3	114.0	113.6	115.1	115.3	118.8
0.2% yield strength (Ksi)	83.3	85.4	90.0	84.0	86.0	84.8	87.1	80.9
Proportional limit (Ksi)	53.0	59.6	62.7	52.3	56.7	57.0	57.1	48.2
Elongation (% in 2 ins.)	4.1	11.0	5.4	11.3	5.3	10.2	6.8	16.3

TABLE XI

SUMMARY OF TENSILE PROPERTIES OF 0.063-inch RENE' 41 ALLOY SHEET
AT ROOM TEMPERATURE AND 1500°F

Heat Treatment Group (See Table I), Strain rates = 0.001 in./in./sec to yield
0.01 in./in./sec to rupture

Tensile Property (Average)	1	2	3	4	5	5a	6	7	8
	Air	Vac	Air	Vac	Air	Air	Vac	Air	Vac
	Room Temperature								
Ultimate tensile strength (Ksi)	171.6	167.9	181.4	177.9	174.5	179.7	176.4	177.5	177.2
0.2% yield strength (Ksi)	115.7	108.4	122.5	120.4	121.3	126.6	116.2	129.2	121.4
Proportional limit (Ksi)	93.0	86.6	94.5	95.0	92.5	101.3	90.2	95.3	93.8
Elongation (% in 2 ins.)	11.3	12.6	13.0	13.1	12.4	11.5	14.3	13.1	12.6
	1500°F								
Ultimate tensile strength (Ksi)	132.5	126.4	124.7	124.0	128.3	126.3	122.1	122.4	114.4
0.2% yield strength (Ksi)	95.6	87.0	95.9	87.3	95.8	92.8	89.8	79.3	79.5
Proportional limit (Ksi)	75.3	65.3	75.3	62.8	74.3	69.6	62.7	56.3	52.0
Elongation (% in 2 ins.)	11.2	21.2	9.8	19.5	17.5	--	18.5	16.8	21.2

TABLE XII

CREEP-RUPTURE OF 0.010-inch RENE' 41 ALLOY SHEET

Test Conditions:

Material = Rene' 41 0.010 in. sheet
Heating = Furnace
Gage length = 2 inches
Atmosphere = Air
Test temperature = 1600°F

Specimen No.	Heat Treat Group (See Table I)	Creep Stress (Ksi)	Time (hrs) to Produce Indicated Plastic Creep					Time to Rupture (hrs)
			0.1%	0.2%	0.5%	1.0%	2.0%	
1	1	25	0.4	1.1	3.3	6.2	10.4	16.3
2		21	0.7	2.1	7.0	13.2	21.8	44.8
3		27	0.2	0.6	1.9	3.5	6.0	11.2
4		18	3.0	7.3	18.4	33.2	55.0	99.8
1	2	23	1.5	3.6	8.5	14.4	23.3	--
2		21	0.6	3.9	14.1	29.5	50.1	99.9
3		27	1.5	2.9	6.0	9.9	15.2	22.5
4		25	3.6	7.0	13.6	20.5	28.7	35.2
1	3	23	0.6	1.4	3.4	6.5	11.5	26.9
2		19	0.6	1.5	4.2	8.7	16.0	38.2
3		26	0.1	0.2	0.8	1.8	3.7	10.1
4		16	1.8	4.0	10.2	19.2	32.6	73.4
1	4	23	0.3	0.9	2.7	5.3	9.6	20.4
2		21	0.6	1.3	3.5	7.0	13.3	33.3
3		25	0.1	0.4	1.1	2.4	4.5	10.9*
4		17	2.0	3.8	8.5	15.2	24.8	60.6
1	5	23	0.6	1.4	3.8	7.4	12.9	31.1
2		19	0.8	2.5	7.3	13.5	22.5	55.2
3		25	0.6	1.2	2.3	4.7	8.2	12.9*
4		16	2.0	4.7	13.7	23.6	37.9	66.4
1	6	23	--	--	--	--	--	49.6
2		21	1.4	3.5	8.9	15.6	26.4	40.1
3		19	4.2	7.9	19.7	28.1	44.0	112.0
4		25	0.4	0.9	2.3	5.5	8.6	20.4
1	7	19	0.8	1.5	4.0	8.1	15.2	48.5
2		25	0.2	0.6	1.5	2.8	5.3	12.1
3		21	0.6	1.6	4.8	9.5	16.4	37.4
4		19	1.0	2.6	7.3	13.2	22.1	50.7
1	8	22	1.0	2.3	6.5	12.6	23.3	51.4
2		20	1.6	4.6	14.0	26.6	43.8	86.1
3		26	0.2	0.6	2.0	4.2	7.9	20.8

* Value probably low

TABLE XIII

CREEP OF 0.063-inch RENE' 41 ALLOY SHEET

Test Conditions:

Heating = Furnace
Heat treatment = Various - Refer to group number in Table I
Gage length = 2 ins.
Atmosphere = Air

Specimen No.	Test Temp. (°F)	Creep Stress (Ksi)	Time (hrs) to Produce Indicated Plastic Creep 0.1%	0.2%	0.5%	1.0%	2.0%	Time to Rupture	Elongation (% in 2 ins.)
			Group 1						
1	1600	26	21.8	31.7	52.5	69.9	88.8	138.3	20
2	1600	23	15.5	36.8	70.0	97.6	--	119.9	2
3	1600	21	33.6	72.4	104.8	139.4	175.6	234.4	9
4	1600	29	12.8	21.2	34.6	45.8	57.9	62.1	8
			Group 2						
1	1600	26	7.0	17.0	46.6	68.3	84.3	120.0	12
2	1600	29	3.0	5.6	15.0	--	--	--	--
3	1600	31	2.0	6.4	16.2	26.6	37.0	68.3	17
4	1600	23	48.0	75.0	103.0	143.6	176.1	210.0	8*
			Group 3						
1	1600	14	Less than 0.05% creep in 116.8 hours, test discontinued						
2	1600	23	27.7	35.9	--	--	--	--	--
3	1600	25	1.0	2.1	5.5	10.8	19.4	(38.9)*	12
4	1600	24	0.8	2.0	6.2	12.5	20.8	(40.1)*	19
5	1600	20	4.2	7.5	17.4	30.3	46.7	83.4	9
6	1600	20	--	--	--	--	--	207.4	5
7	1600	27	4.8	8.7	16.0	22.8	30.5	35.6	8
8	1600	31	2.2	4.2	7.8	11.3	15.9	27.0	14
			Group 4						
1	1600	16	94.6	160.6	--	--	--	--	--
2	1600	24	3.3	6.4	14.6	25.3	39.2	75.5	23
3	1600	21	1.9	6.8	21.2	40.1	63.6	120.2	12
4	1600	29	0.5	0.7	2.0	3.3	5.7	21.1	--

* = Heat treatment, see Table I

TABLE XIII (Continued)

Specimen No.	Test Temp. (°F)	Creep Stress (Ksi)	Time (hrs) to Produce Indicated Plastic Creep 0.1%	0.2%	0.5%	1.0%	2.0%	Time to Rupture (hrs)	Elongation (% in 2 ins.)
			Group 5						
1	1600	22	0.4	1.1	3.7	7.3	13.0	65.4	21
2	1600	26	0.5	1.3	3.3	6.0	9.9	(19.1)*	12
3	1600	19	2.5	5.8	15.0	29.8	51.0	104.7	11
4	1600	18	Run 161.5 hrs, no measurable creep					--	--
			Group 6						
1	1600	26	0.7	11.4	13.7	16.8	20.4	29.5	31
2	1600	23	8.6	11.6	21.0	28.9	41.6	107.4	22
3	1600	27	0.1	0.2	0.8	211	4.7	14.5	15
4	1600	20	2.0	4.4	--	--	--	103.1	--
5	1600	27	0.6	1.3	2.7	4.2	--	20.3	28
6	1600	25	0.5	1.0	2.6	5.1	8.2	31.6	20
			Group 7						
1	1600	20	3.8	15.5	--	--	--	--	--
2	1600	30	0.1	0.3	0.7	1.5	2.8	(6.5)*	5
3	1600	23	0.3	1.2	4.6	9.2	16.2	(36.1)*	5
4	1600	19	--	--	--	--	--	87.8	22
5	1600	27	0.4	0.8	2.0	4.1	7.4	23.1	30
			Group 8						
1	1600	23	0.6	1.9	6.0	13.1	23.4	47.4	16
2	1600	26	0.3	1.0	1.5	3.2	6.3	22.5	26
3	1600	20	1.2	2.6	6.9	13.5	24.1	71.2	17

* = Heat treatment, see Table I

STRESS RUPTURE AND CREEP OF 0.010-inch RENE' 41 ALLOY SHEET AT 1600° F,
HEAT TREAT GROUP 1

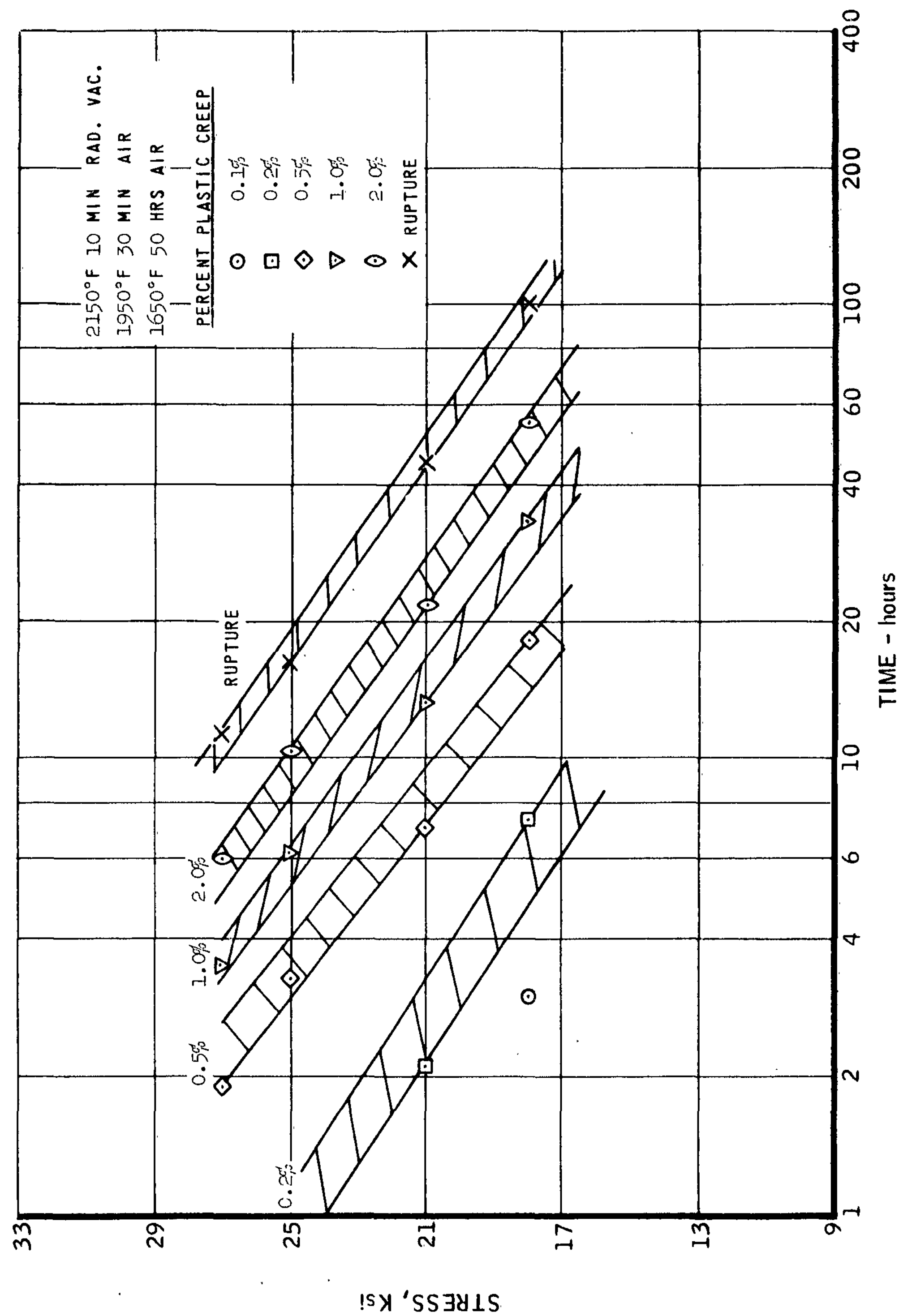
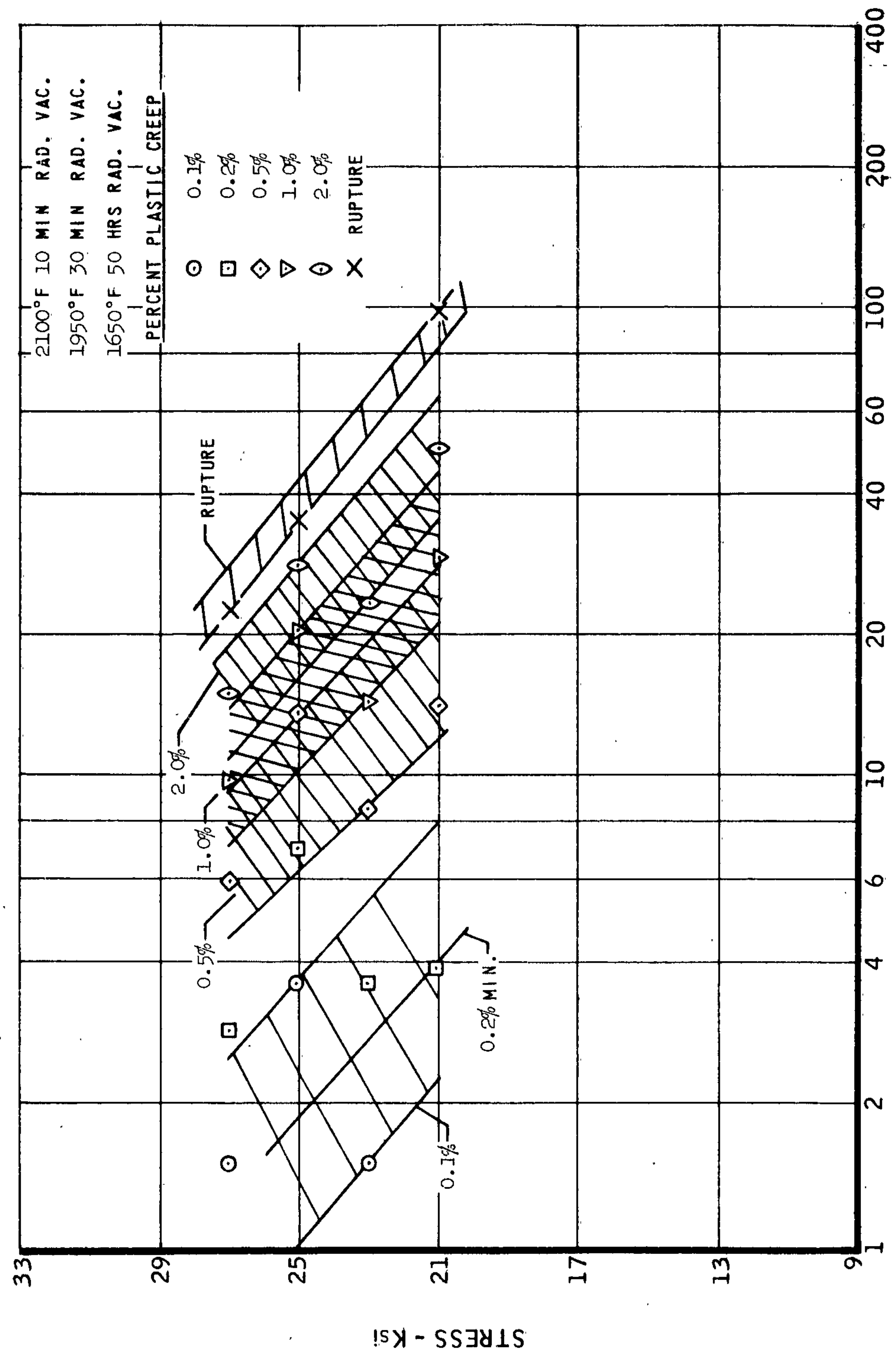
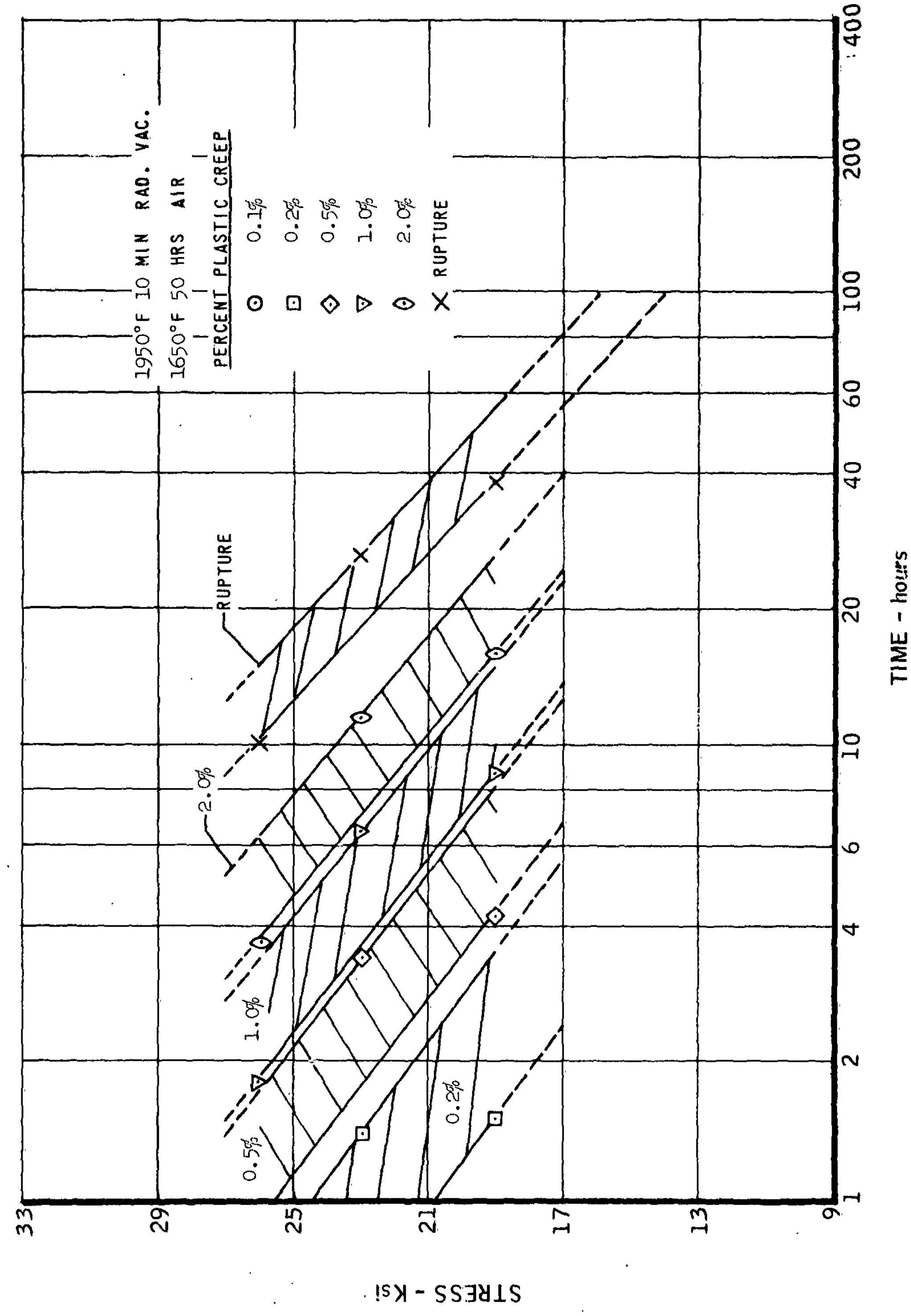


FIGURE 1

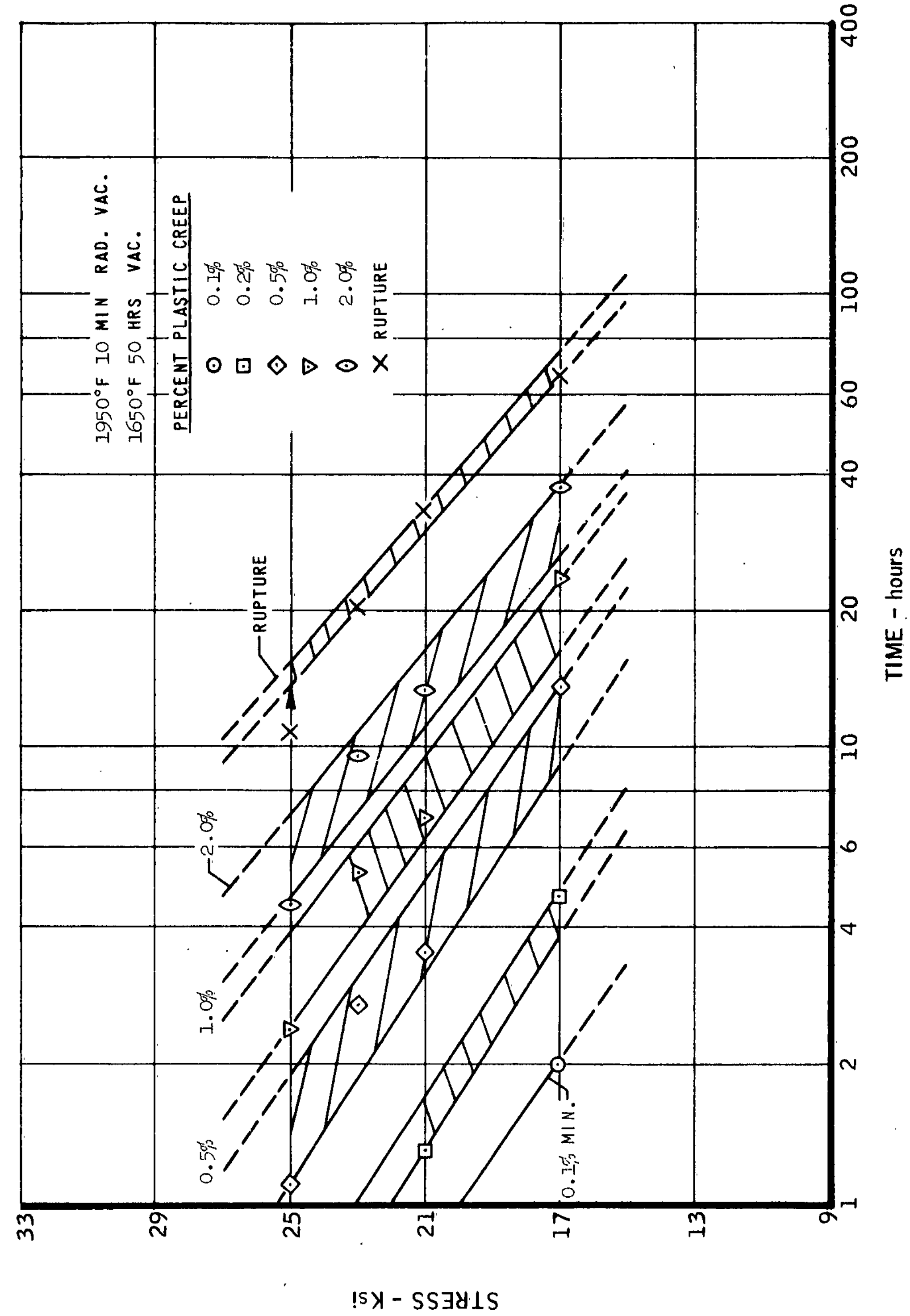
STRESS RUPTURE AND CREEP OF 0.010 - inch RENE' 41 ALLOY SHEET AT 1600° F,
HEAT TREAT GROUP 2



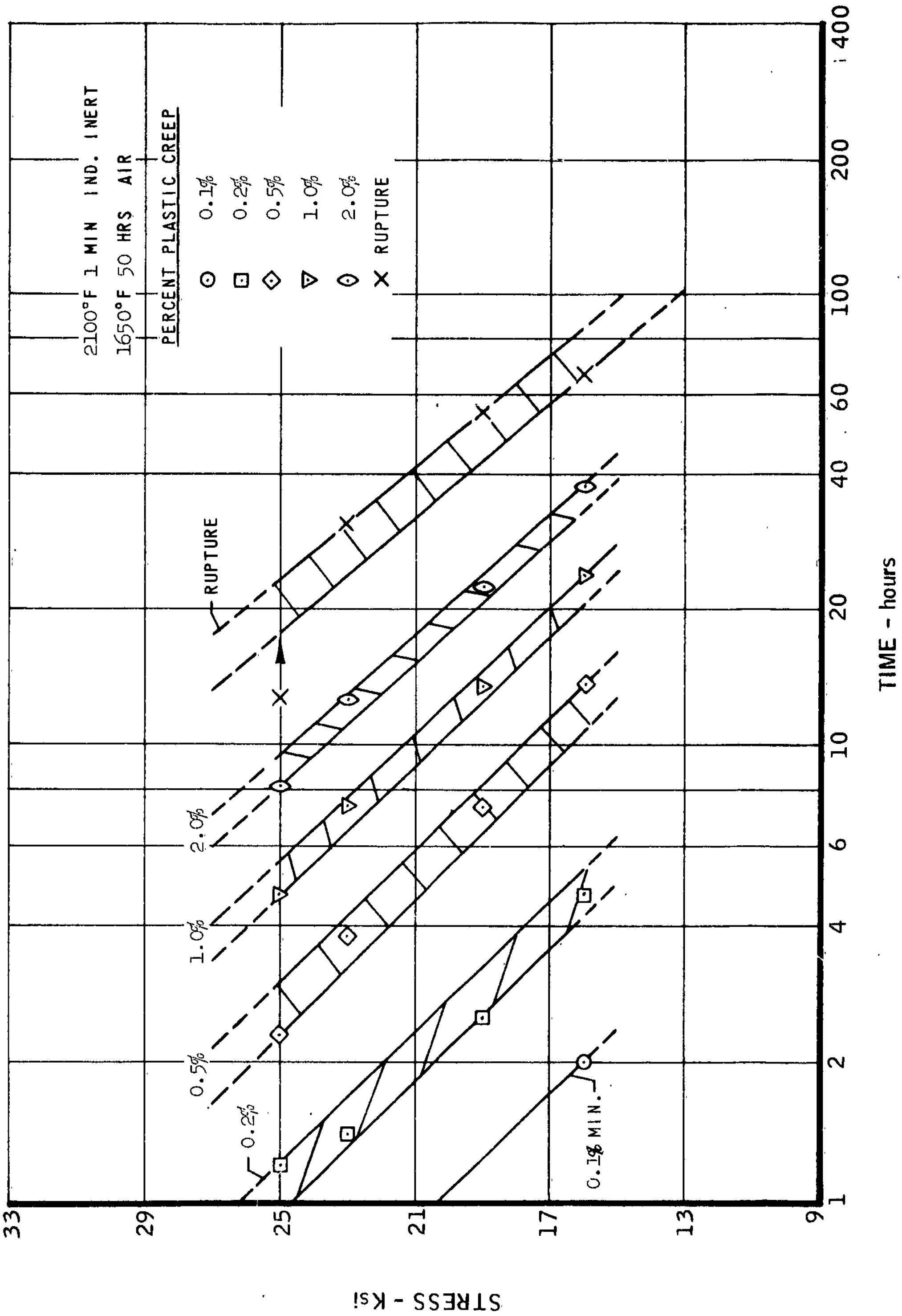
STRESS RUPTURE AND CREEP OF 0.010-inch RENE' 41 ALLOY SHEET AT 1600° F,
HEAT TREAT GROUP 3



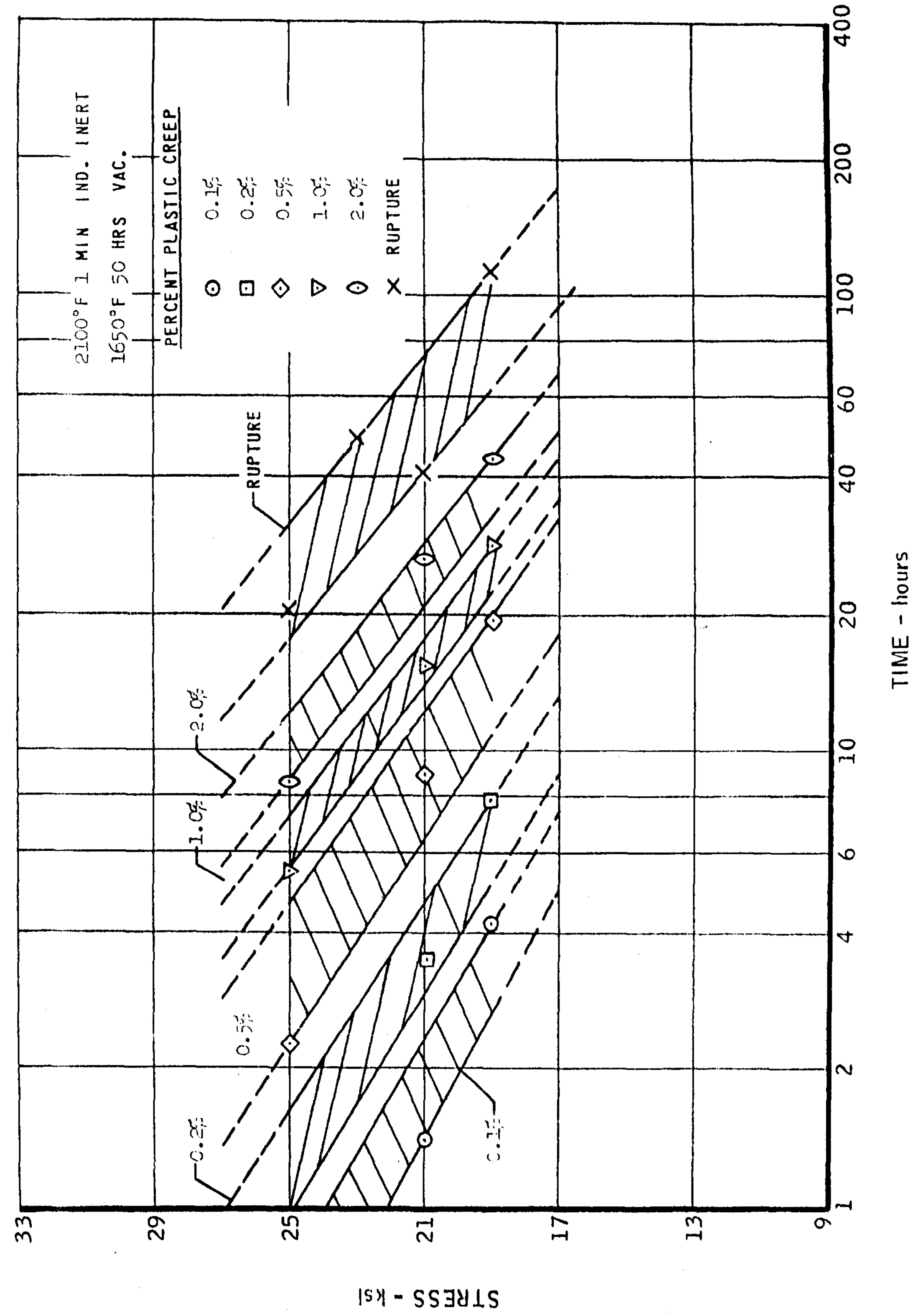
STRESS RUPTURE AND CREEP OF 0.010-inch RENE' 41 ALLOY SHEET AT 1600° F,
HEAT TREAT GROUP 4



STRESS RUPTURE AND CREEP OF 0.010 - inch RENE' 41 ALLOY SHEET AT 1600° F,
HEAT TREAT GROUP 5



STRESS RUPTURE AND CREEP OF 0.010 - inch RENE' 41 ALLOY SHEET AT 1600° F,
HEAT TREAT GROUP 6



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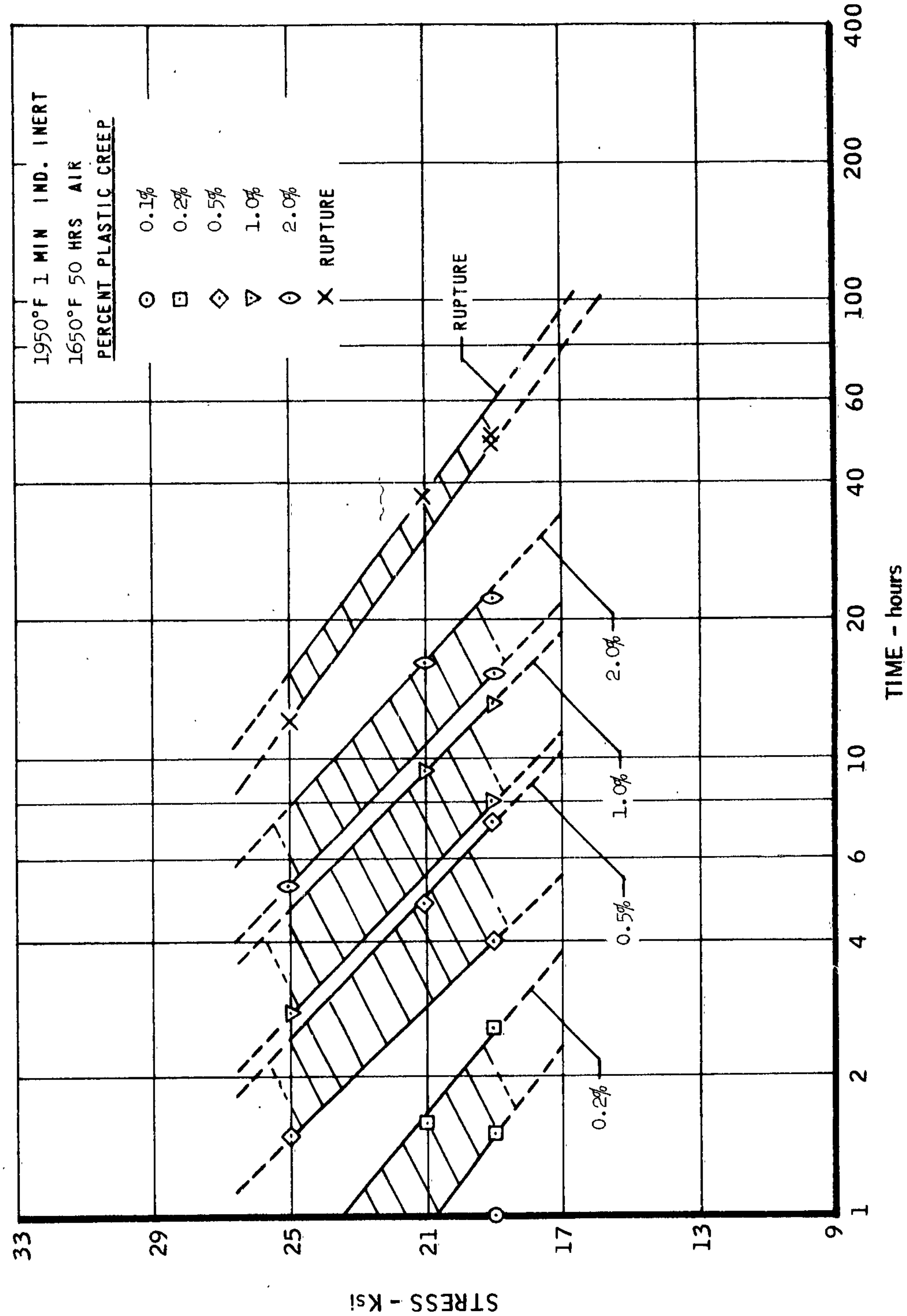
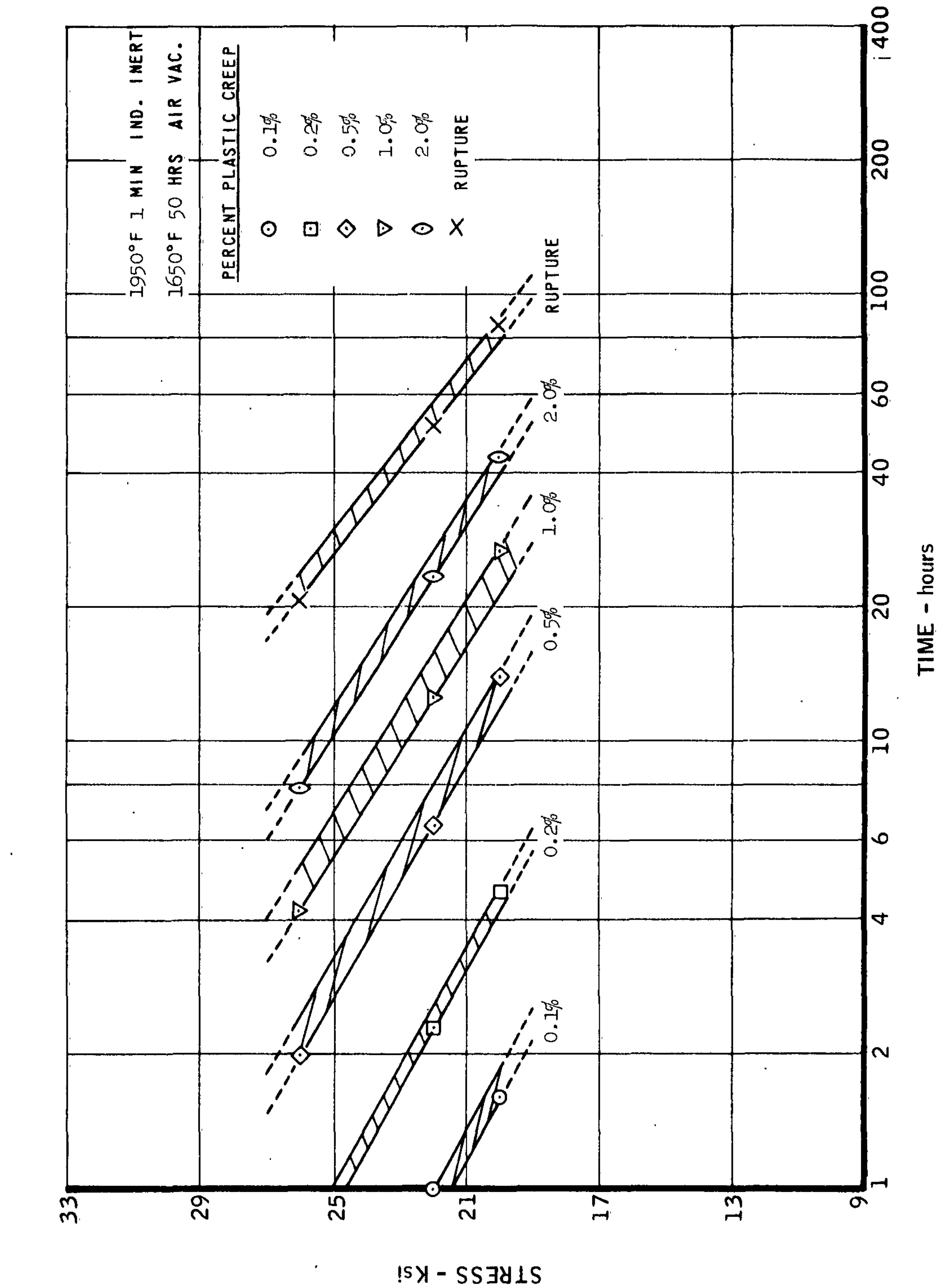
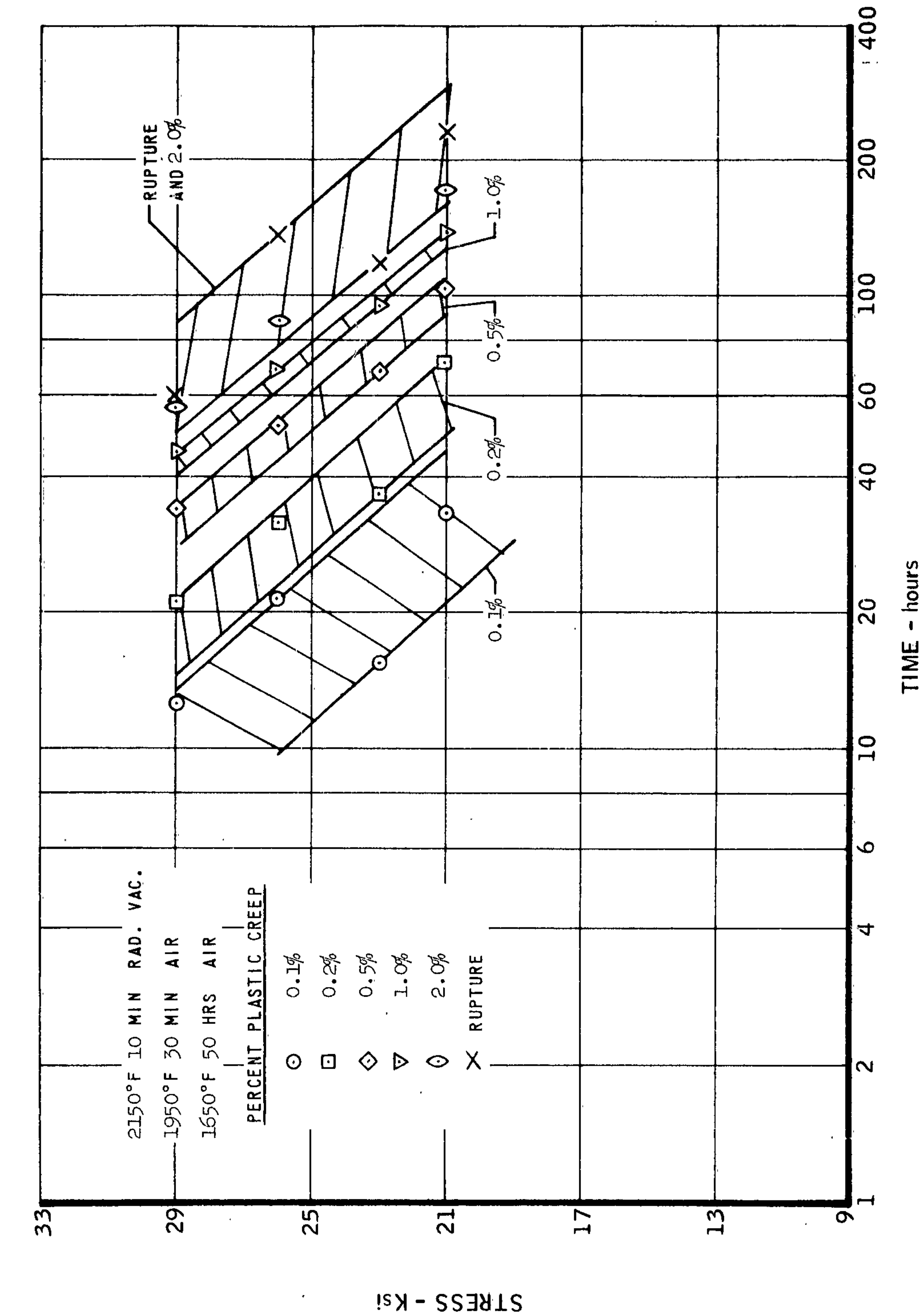
STRESS RUPTURE AND CREEP OF 0.010 - inch RENE' 41 ALLOY SHEET AT 1600° F, HEAT TREAT GROUP 7

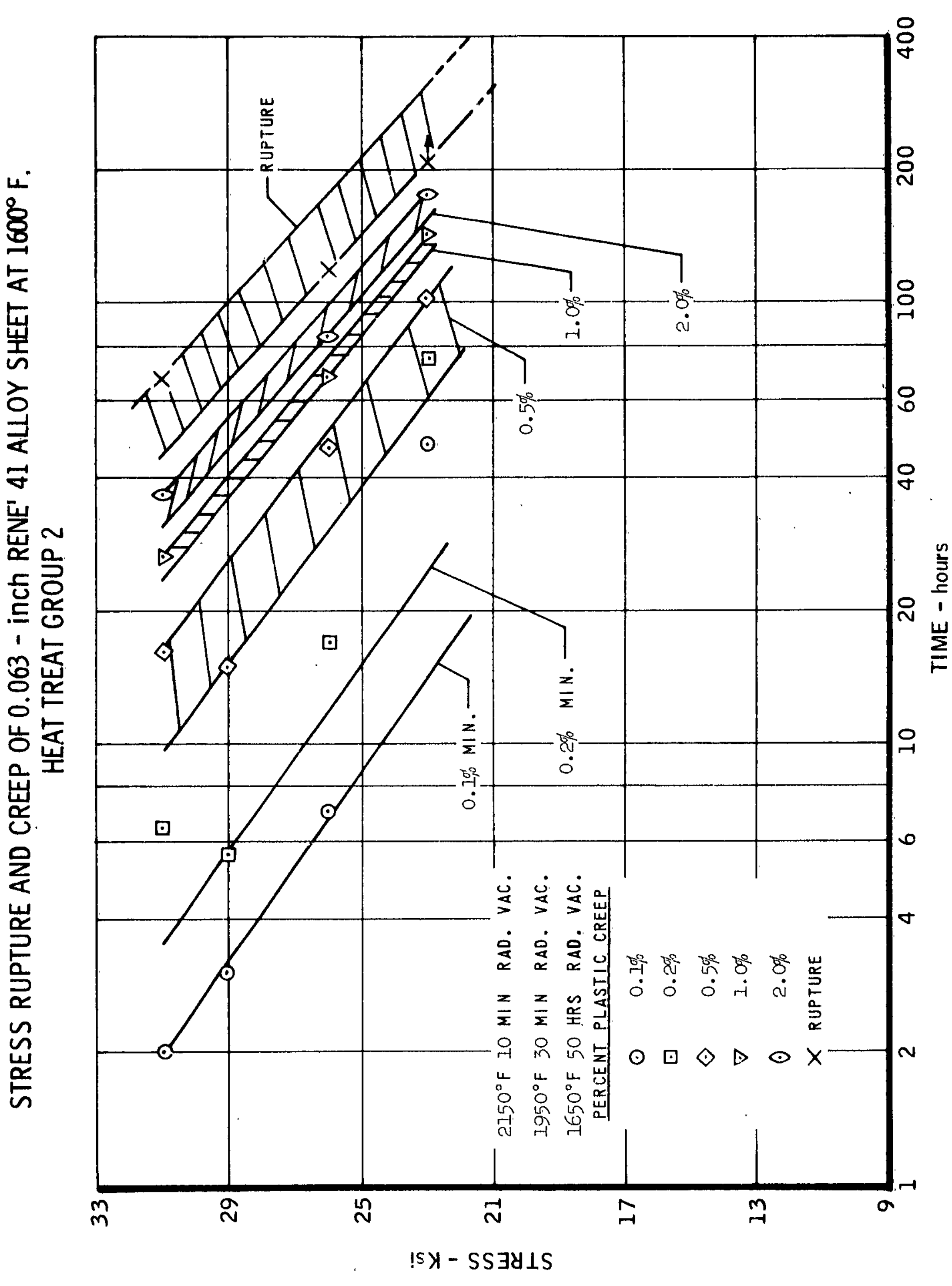


STRESS RUPTURE AND CREEP OF 0.010 - inch RENE' 41 ALLOY SHEET AT 1600° F,
HEAT TREAT GROUP 8



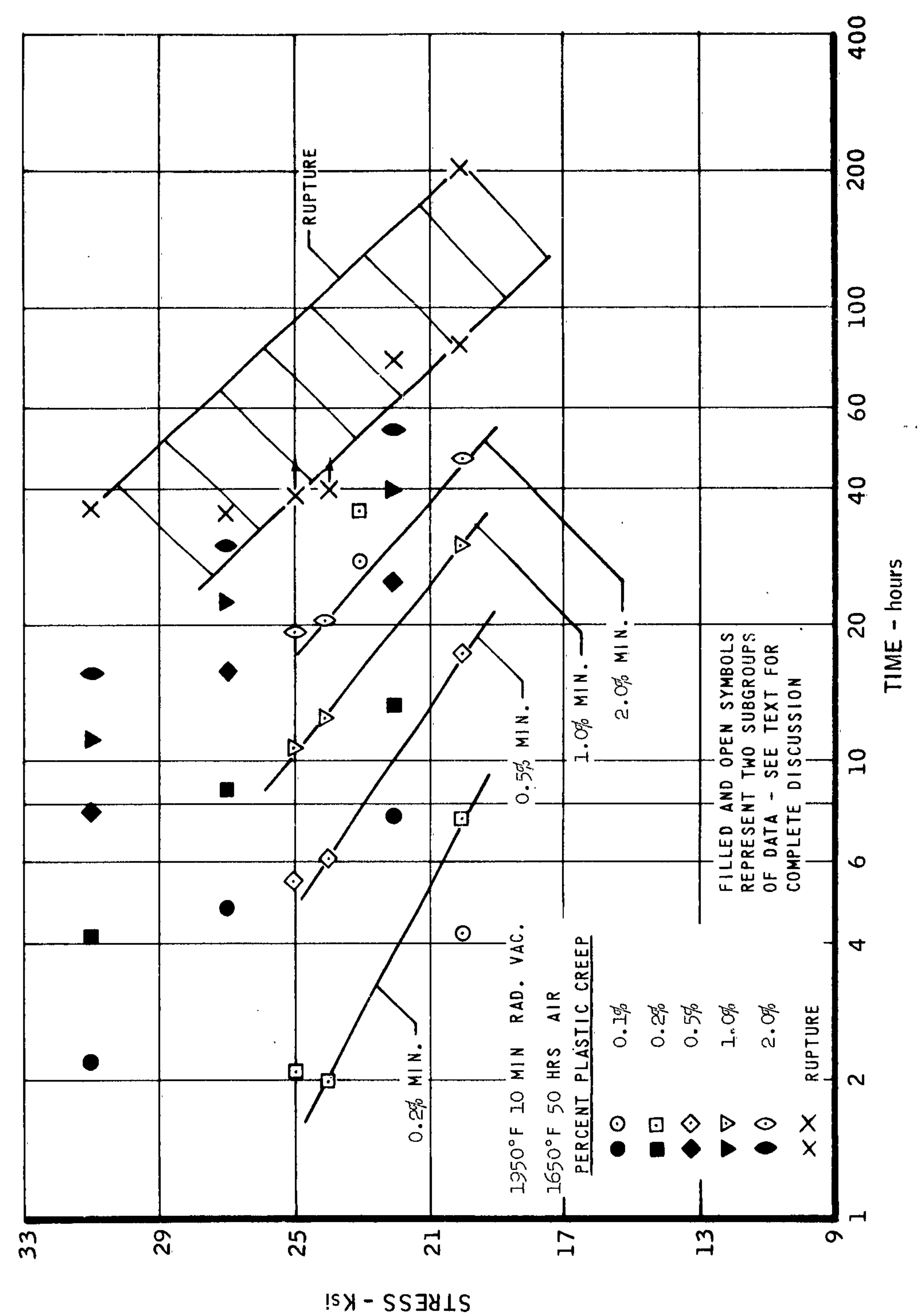
STRESS RUPTURE AND CREEP OF 0.063-inch RENE' 41 ALLOY SHEET AT 1600° F,
HEAT TREAT GROUP 1





STRESS RUPTURE AND CREEP OF 0.063 - inch RENE' 41 ALLOY SHEET AT 1600° F.
HEAT TREAT GROUP 2

STRESS RUPTURE AND CREEP OF 0.063 - inch RENE' 41 ALLOY SHEET AT 1600° F, HEAT TREAT GROUP 3



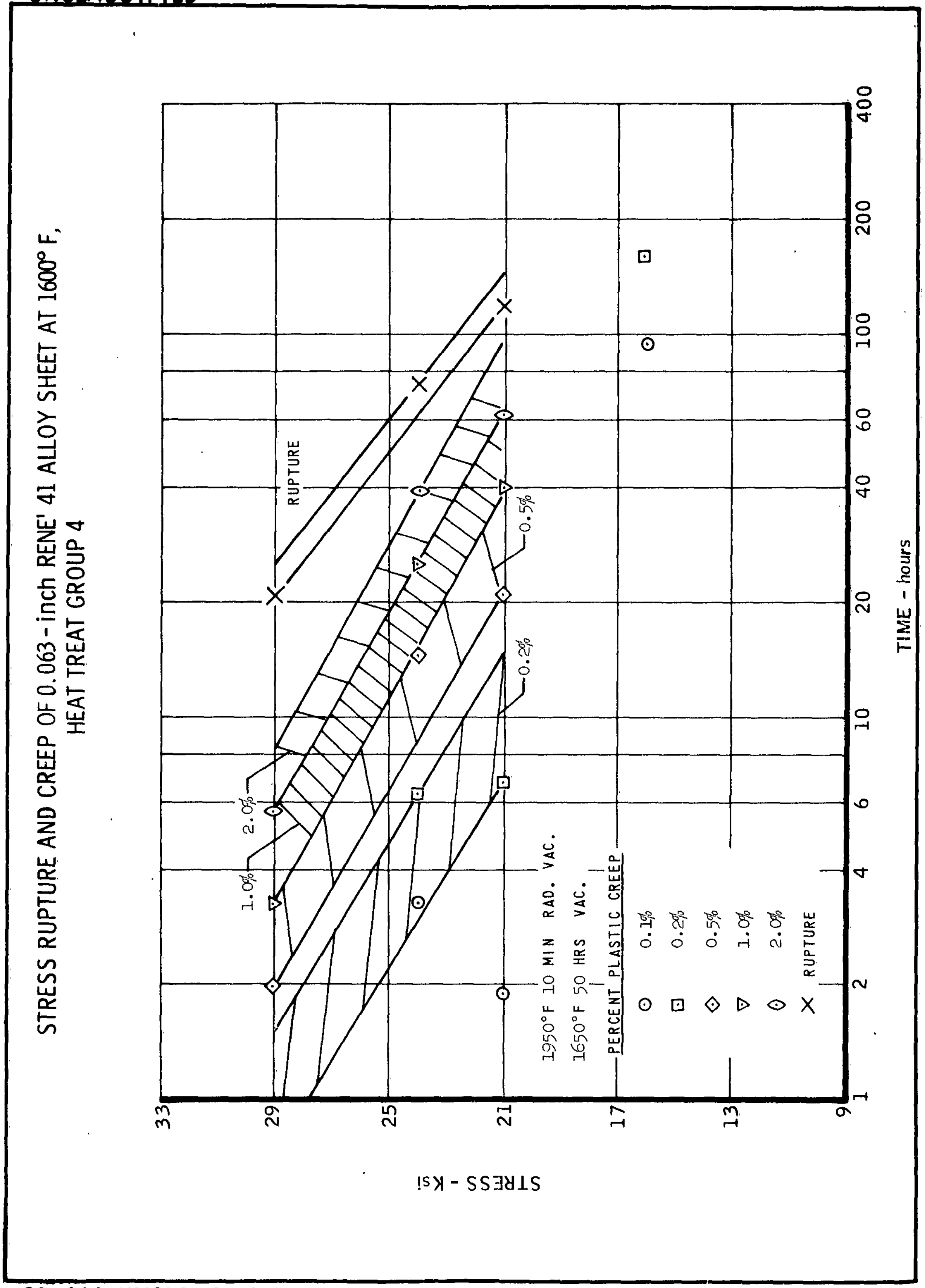
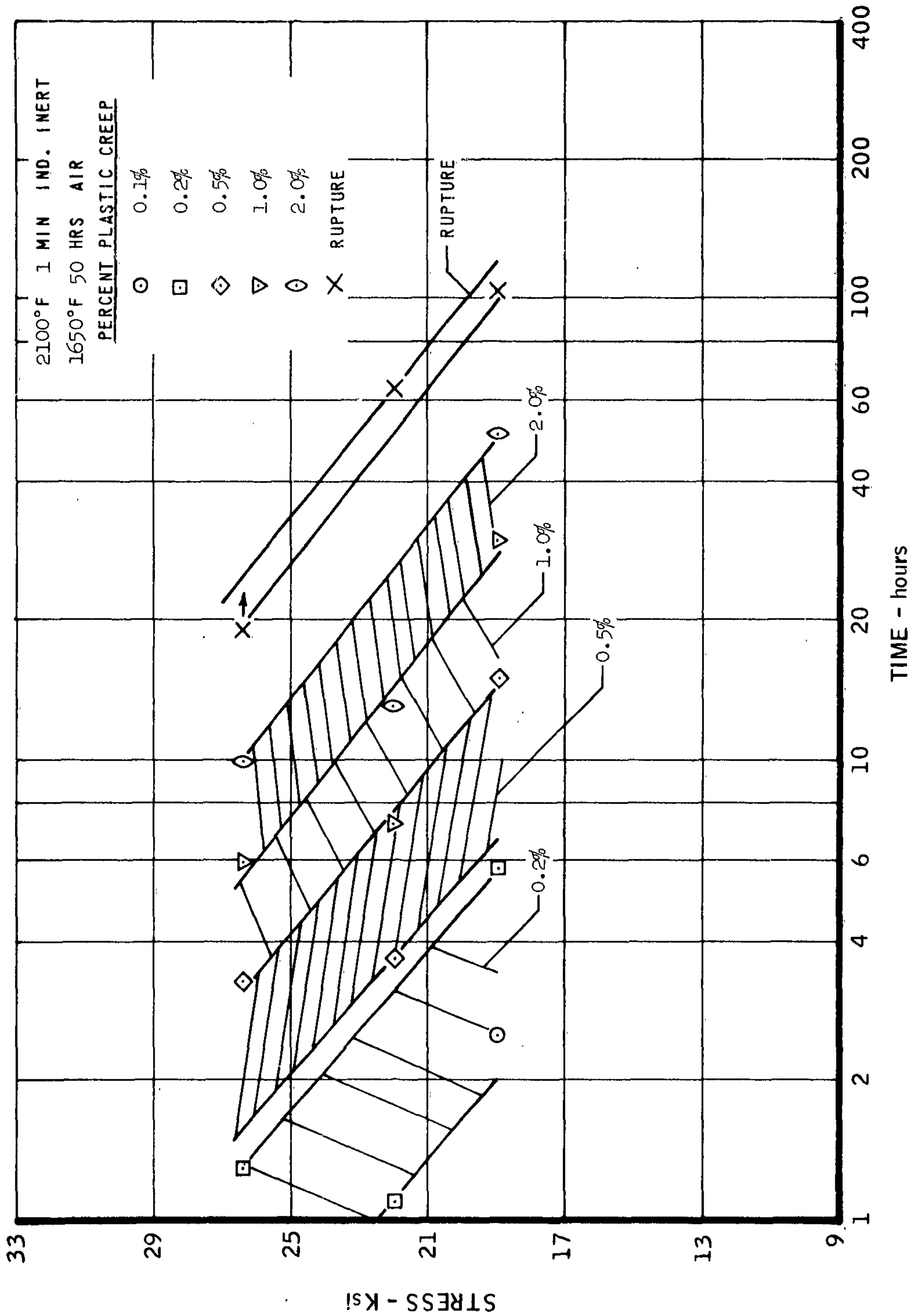
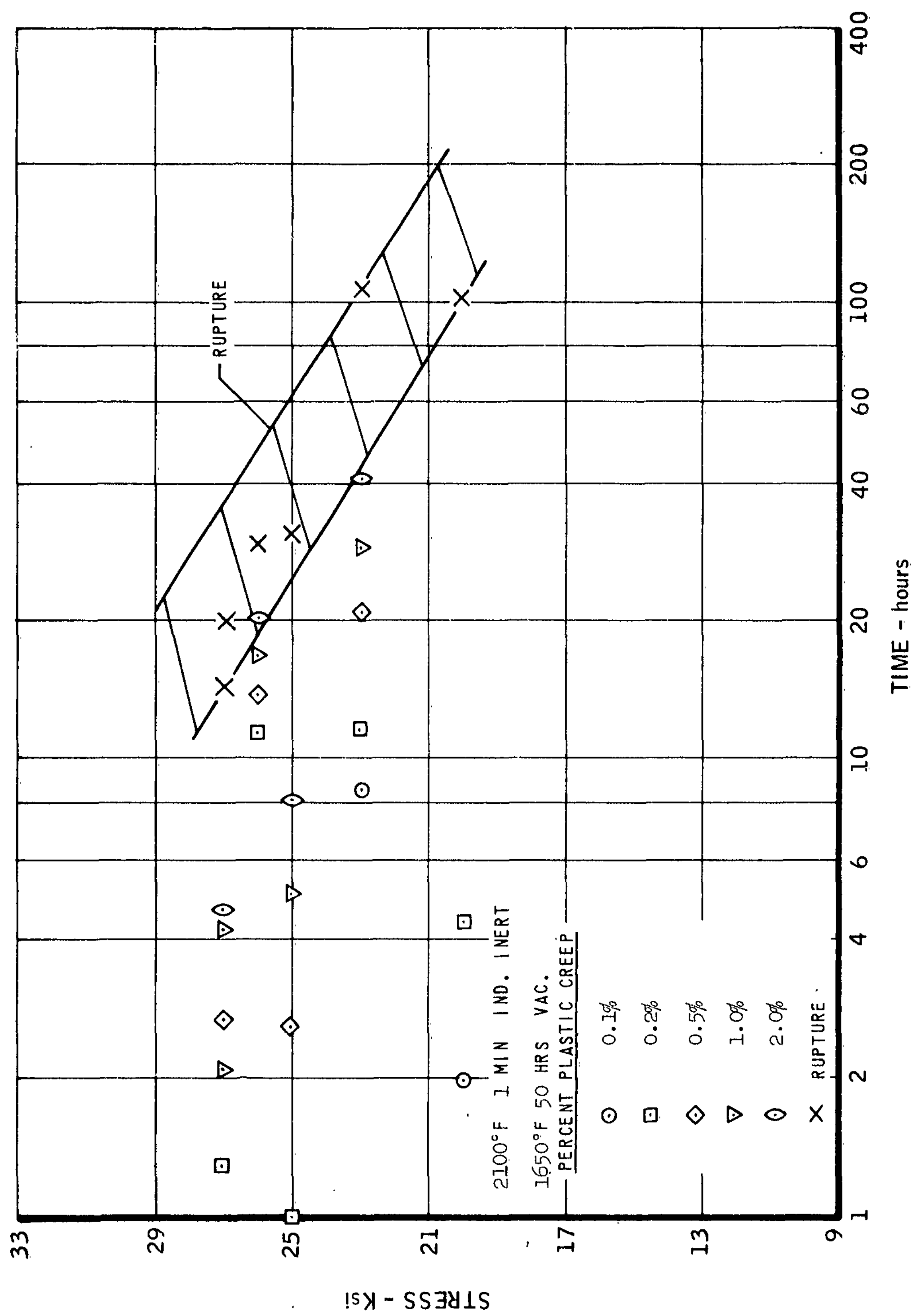

STRESS RUPTURE AND CREEP OF 0.063-inch RENE' 41 ALLOY SHEET AT 1600° F,
HEAT TREAT GROUP 4
RUPTURE
2.0%
1.0%
0.5%
0.2%
1950°F 10 MIN RAD. VAC.
1650°F 50 HRS VAC.
PERCENT PLASTIC CREEP
0.1%
0.2%
0.5%
1.0%
2.0%
RUPTURE
STRESS - Ksi
33
29
25
21
17
13
9
TIME - hours
1
2
4
6
10
20
40
60
100
200
400

FIGURE 12

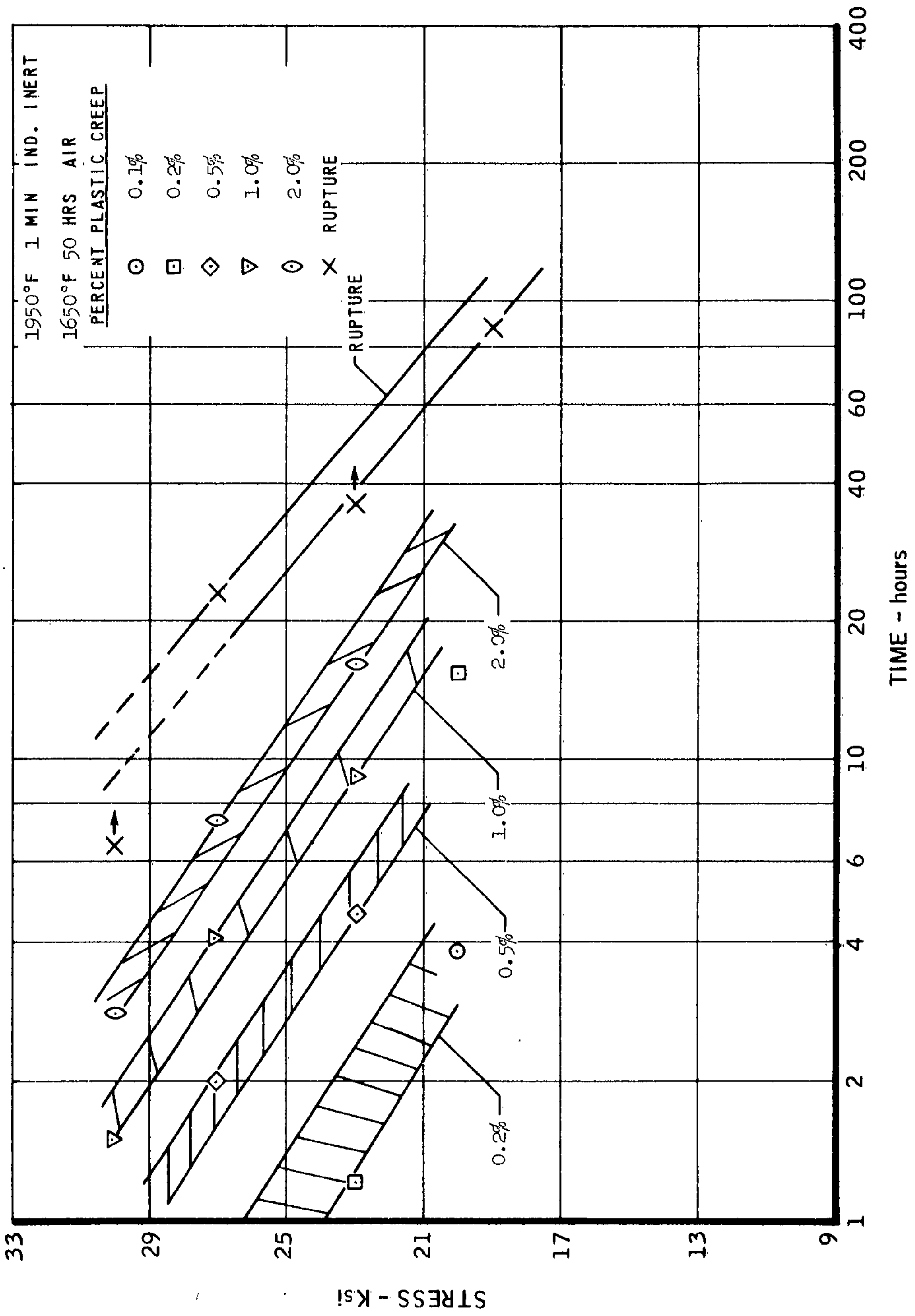
STRESS RUPTURE AND CREEP OF 0.063-inch RENE' 41 ALLOY SHEET AT 1600° F,
HEAT TREAT GROUP 5



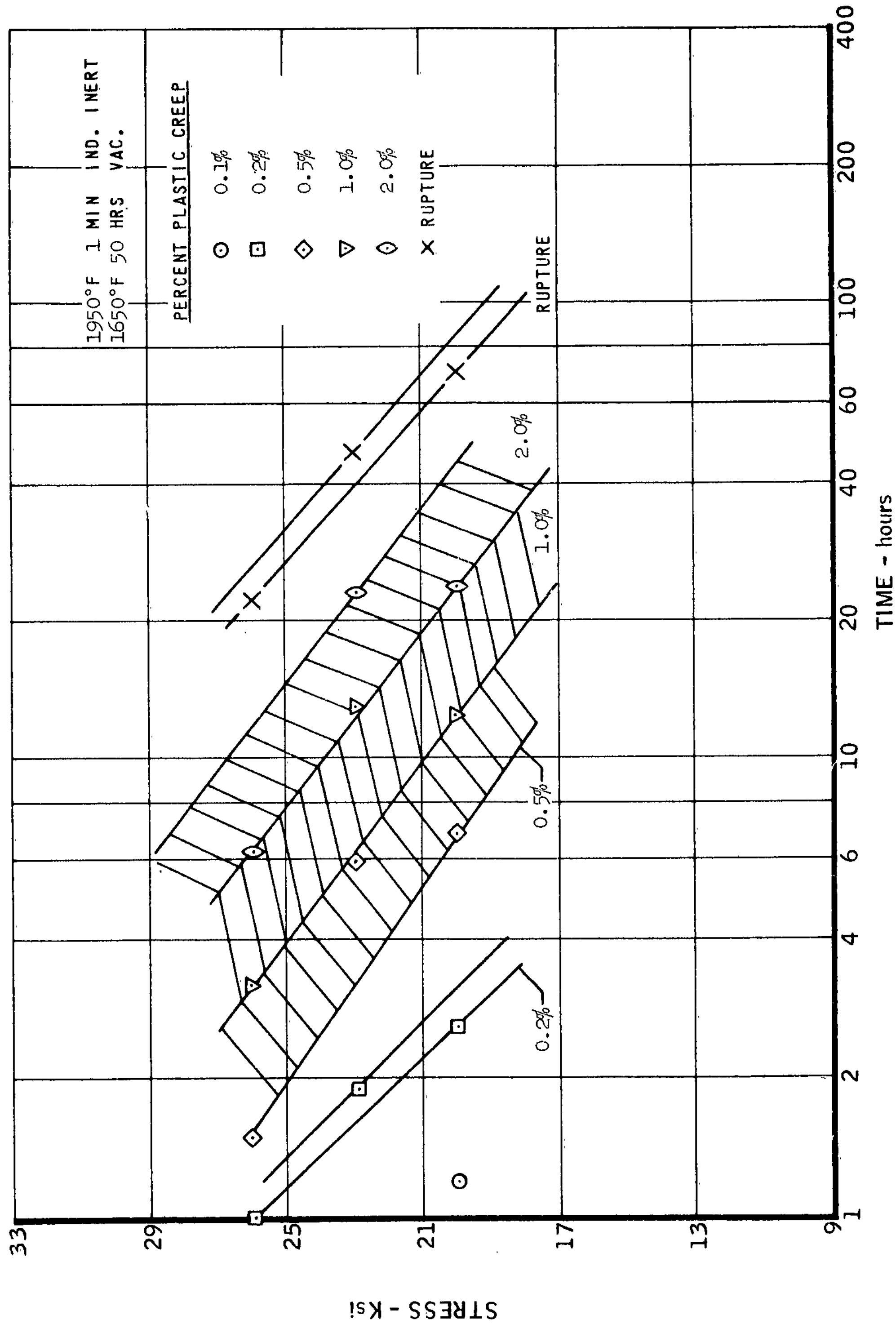
STRESS RUPTURE AND CREEP OF 0.063 - inch RENE' 41 ALLOY SHEET AT 1600° F,
HEAT TREAT GROUP 6



STRESS RUPTURE AND CREEP OF 0.063 - inch RENE' 41 ALLOY SHEET AT 1600° F,
HEAT TREAT GROUP 7



STRESS RUPTURE AND CREEP OF 0.063 - inch RENE' 41 ALLOY SHEET AT 1600° F,
HEAT TREAT GROUP 8



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